Bulletin of Glaciological Research 23 (2006) *95–99*

Water levels and temperatures in moulins, and other hydrological observations at Bashkara Glacier in Caucasus, Russia, in September 2005

Evgeny ISENKO

Institute of Low Temperature Science, Hokkaido University, Sapporo 060–0819, Japan

(Received October 7, 2005; Revised manuscript accepted November 9, 2005)

Abstract

In order to investigate hydrology and, in particular, drainage systems of glaciers, measurements of water temperatures and water levels in moulins, water temperatures along glacial surface water streams, and other glacio-speleological observations were carried out at Bashkara Glacier in Caucasus, Russia, from 10 to 14 September, 2005. Extremely high amplitude of water level oscillations in moulins demonstrates plausibility of the approach, when a channel consists of a wide vertical part (moulin) and narrower subhorizontal part deep in a glacier. Water temperature measurements in one of the moulins revealed that it grows with the distance from the glacier surface, but much quicker than estimated by the loss of potential energy. It probably means that the heat exchange with the air is much more significant than was expected.

1. Introduction

The water flowing on the glacier surface and penetrating into the inner and subglacial parts makes a complicated channel network, consisting of surface streams, moulins (vertical shafts), intraglacial pressurized or open conduits, and subglacial tunnels. The question of where and how water circulates within glaciers is of considerable interest from various points of view (Röthlisberger, 1972). Knowing the structure of a glacial drainage system and the parameters of the water flowing through it, we can understand glacier dynamics, inner ablation, outflow hydrograph and other hydrological processes.

Glacial water channels, or glacial caves, can also be a subject of speleological interest. Collaboration between glaciologists and speleologists started with the rapid development of speleology in the middle of the 20th century, when a lot of speleologists actively studied glacier caves and caverns (Potts, 1950; Halliday, 1954). Nevertheless, even now such joint expeditions are very seldom, although they give glaciologists unique possibility of exploring the subject of their study directly from inside. Moreover, most of the reports on glacial moulins explorations (Badino 1999; Holmlund, 1988; Reynaud, 1987) contain mainly qualitative results, rather than the results of strict measurements.

The field work on Bashkara Glacier in Caucasus, Russia, that was carried out from 10 to 14 of September, 2005, was exactly such a speleo-glacio- joint expedition. We measured water temperature and registered water level oscillations, along with mapping, in two largest moulins, traced water temperatures along two glacial surface water streams, and conducted some other glacio-speleological and hydrological observations.

2. Study area

Bashkara Glacier is placed in the Central Caucasus about 40 km south-east from Mt. Elbrus just near well studied Djankuat Glacier. Bashkara Glacier is relatively large. Its total length is about 4 km, and maximum ice thickness is thought to be about 200 m. The accumulation area (Fig. 1) is situated on the steep slopes of several 4000 m peaks, heavily crevassed, with a lot of avalanche areas and ice-falls that makes mass-balance measurements almost impossible there. In contrary, the ablation area is almost flat, with many water streams and moulins, and easy to explore.

There are a large ice-dammed lake in the middle part of the tongue and several small moraine-dammed lakes near the terminus. All these lakes are supposed to be outburst-dangerous (for example, Chernomorets, 2005), although not everybody shares this opinion. There are not so many glaciers with lakes in that area, and this is one of the reasons, by which Bashkara Glacier attracts attention of many glaciologists. The small lakes continue to grow. One of the lakes, ap-

Fig. 1. The accumulation area and the upper part of the ablation area of Bashkara Glacier. The moulins are marked by the arrows.

Fig. 2. The newly formed lake at the glacier terminus.

peared during the last three years in the ice at the tongue (Fig. 2), is ice-dammed, and the dam is expected to be melted away in two or three years. In that case, the east part of the glacier terminus would retreat sharply by more than 100 m.

A huge tunnel at the west side of the terminus, from where most of the water discharge (about 2 m^3 s^{-1}) occurs, exists at least during the last several years (Fig. 3). According to our survey, its width and height in the widest part is 18 m and 5 m respectively. By water traces on the ice wall, we concluded that it was completely flooded recently.

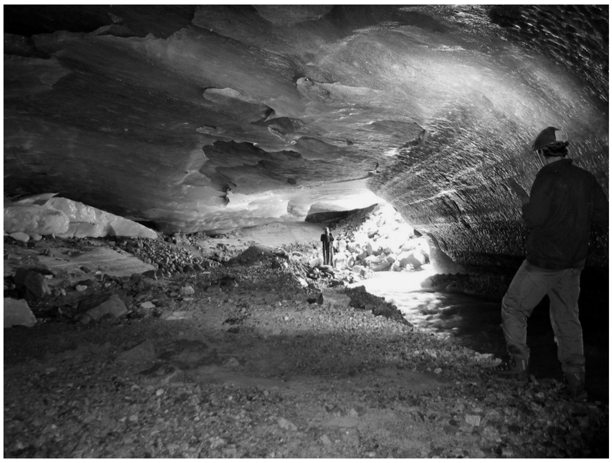

Fig. 3. A huge tunnel at the west side of the glacier terminus.

Because the glacier tongue is relatively flat and with a few crevasses, a lot of water flows on the surface and mostly make a way into the ice through moulins. Two large and one small moulins, as well as two long surface water streams were the subject of our measurements.

3. Members

The expedition was put just after the Conference on Glacier Caves and Karst in Polar Regions that was held near the same region from 5 to 9 of September, 2005. The idea of the expedition was proposed by the author as a continuation and an important experience for participants of the conference. However, only six could take part in the field work.

Research group:

Dr. Bulat Mavlyudov (Institute of Geography, Russian Academy of Sciences). Leader, Glaciologist

Dr. Evgeny Isenko (Institute of Low Temperature Science, Hokkaido University), Glaciologist

Dr. Pavel Sivinskih (Perm State University), Speleologist

A team of experienced cavers:

Mr. Yuri Kosorukov (Russia), Mr. Ryo Matsuzawa (Japan), Ms. Olga Chervetsova (Russia)

4. Measurements

The water temperature in two longest glacier surface water streams were measured with the distance step of 5 to 50 m depending on the local conditions. We used a waterproof digital thermometer CT-800WP with a sensor LK-800WP (accuracy 0.1℃). The first stream (total length 445 m) begins from the most upper part of the ablation zone, slightly covered by fresh snow, as several small (3–5 l s^{-1}) streams. It flows along the middle moraine and finally drops into the moulin, where discharge reaches up to 50 l s^{-1}. Water flow

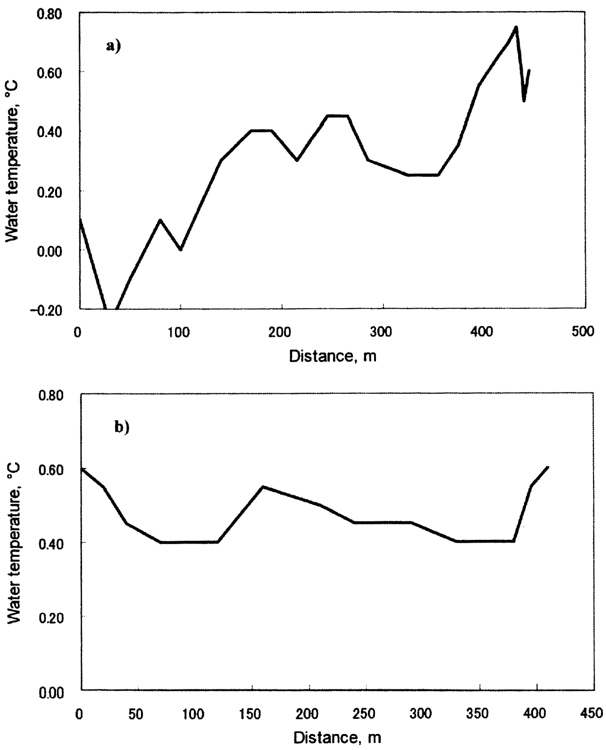

Fig. 4. Water temperature profile along surface water streams. a) at the upper part of the ablation area; total length 445 m, discharge from 2–3 to 50 l s^{-1}. b) near the terminus; total length 410 m, discharge from 3 to 30 l s^{-1}.

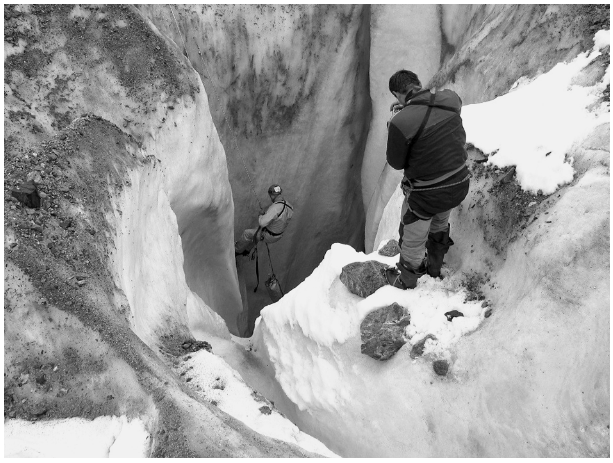

Fig. 5. The entrance pit to the deepest (−57 m) moulin (the moulin B).

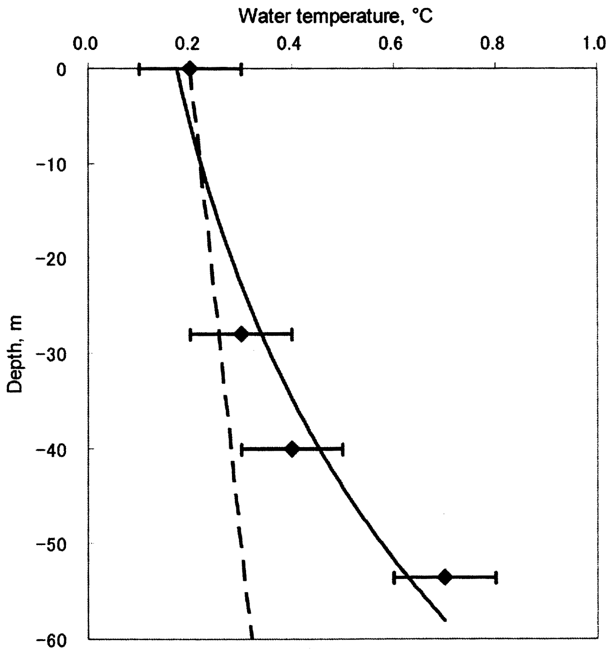

Fig. 7. Vertical profile of water temperature in the moulin B. The maximum rate of water temperature increase, estimated by the loss of potential energy, is shown by the dashed line.

discharges were calculated by the measurements of water flow speed and channel size. The second stream (total length 410 m) is situated much more downstream and begins from moraine covered ice surface. The results of the water temperature measurements are shown in Fig. 4.

When we tried to explore two large moulins, we faced with the problem that they were flooded up to the level of about −20 m from the glacier surface. However, in the early morning, when the water discharge was minimal, we managed to descend deeper −50 m. In the moulin A we reached the water, which level was rising approximately 2–4 m per hour at that time. In the moulin B (Fig. 5) we could not reach the water level and stopped at the depth −57 m because of lack of the ice-screws. The map (profile sweeping and top view) of the moulin B is shown in Fig. 6 and the vertical profile of water temperature is shown in Fig. 7.

5. Discussion

The structure and evolution of glacial drainage systems depend on a plenty of factors and one of the significant ones is the water temperature, because it controls the melting rate on the channel walls. The water temperature can vary along its flow line because the water temperature depends on the air temperature, solar radiation, the flow discharge, the amount of sediments, and also the channel's form, size, and slope. According to Isenko *et al.* (2005), the temperature of water flowing in a glacial channel tends to the equilibrium, whose value is usually less than 0.1℃, unless there is no environmental influence such as heat exchange with the air or warming by the solar radiation. Otherwise, the water temperature can rise up to much higher values as in our case. Two examples of water temperature profile along the stream line are shown in Fig. 4. It is very difficult to explain all changes in the temperatures in the graphs, because in this case we have to measure strictly a huge number of parameters, such as channel geometry, sediments

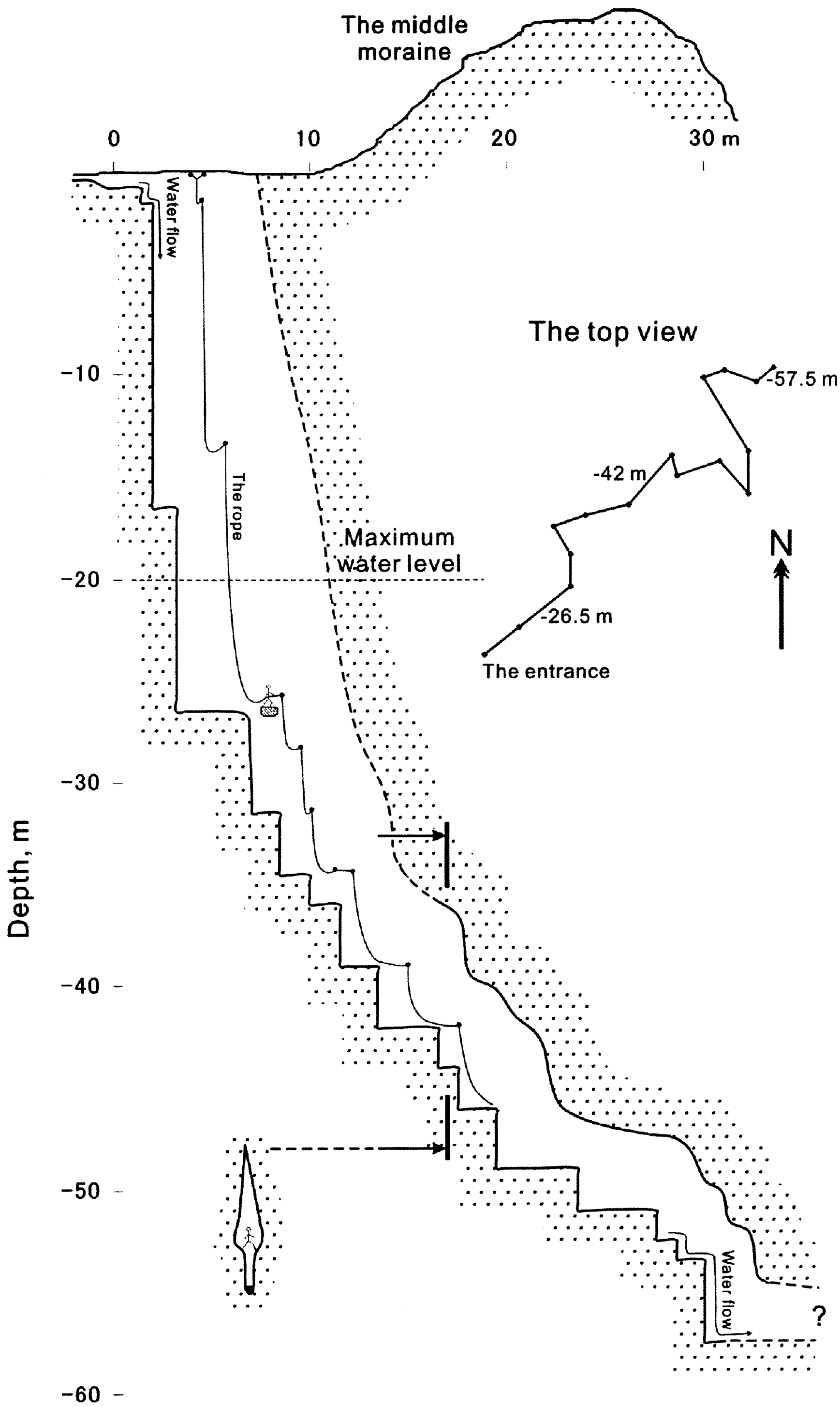

Fig. 6. The map (profile sweeping and top view) of the moulin B. The right boundary and the ceiling of the upper part of the moulin are unclear, that illustrated by the dashed line.

quantity, distribution and albedo, solar radiation, air temperature, wind speed, and so on.

Both streams were heavily sedimented. Sediments make the heat exchange between ice and water more difficult (Isenko *et al.,* 2005). Therefore the water temperatures should be rather high. In the case of the water stream that originates from a snow covered area (Fig. 4a), water temperature rises gradually from ~0℃ to 0.4 ~ 0.6℃. In the case of the water stream that originates from the moraine (Fig. 4b), temperature of water drops a little, when water enters the area of pure ice, and then rises to the usual value. From both graphs we can see that the water temperature responds to the changes in the channel very quickly (20–50 m along the flow). It means that the temperature balance in the water is near the equilibrium almost at all points along the stream.

Direct consequence of the energy conservation law indicates that the lost of potential energy for some volume of water is sufficient for its warming by 0.2℃ each 100 m of lowering (Zotikov, 1982). Usually this warming is much lower because of the heat exchange with the ice (Isenko *at al.,* 2005). Nevertheless, water temperature in one of the vertical shafts (moulins), that we explored, increased with depth with unexpectedly high rate (Fig. 7). The maximum rate of water temperature increase, estimated by the loss of potential energy, is shown by the dashed line. This can be explained only by an extreme high rate of the heat exchange with the air in the vertical parts (waterfalls), where the continuous water stream turns into drops and smaller streams. However, we need more statistics to make more profound conclusions.

Typically, the upper part of an intraglacial channel is wide, non-pressurized, and usually vertical (shafts, moulins). The lower part is narrower because of ice contraction, completely filled with water (pressurized), and usually subhorizontal (Badino 1999; Holmlund, 1988; Isenko, 2005; Reynaud, 1987). Water level in the upper part of such a channel should change responding to changes of both water flow discharge and channel size. Our observations did show such water level oscillations: the amplitude in the moulin A was about 30 m and more than 40 m in the moulin B. These changes in water level are supposed to be diurnal or at least weather dependant.

6. Acknowledgment

I express my sincere thanks to Bulat Mavlyudov, who undertook all organization of the expedition and provided all participants with the permits to the frontier area. I also thank and express my respect to Yuri Kosorukov — one of the most experienced cavers in Russia — for speleo- and ice-climbing outfit support and supervising during glacier caves explorations. Collaboration with all other participants of the expedition was also extremely fruitful.

My personal participation was supported by the Inoue Field Study Foundation in April, 2005.

I am grateful to N. Azuma of Nagaoka University of Technology and R. Naruse of Institute of Low Temperature Science for their critical comments on the manuscript.

References

Badino, G. (1999): The glacial carst. NIMBUS, 23/24, 82–93.

Chernomorets, S. S. (2005): Mudflow areas before and after catastrophe. “Nauchny Mir”, Moscow, 184 p. (In Russian).

Halliday, W. R. (1954): Ice caves of United States. NSS Bull., v. **16**, 3–28.

Holmlund, P. (1988): Internal geometry and evolution of moulins, Storglaciären, Sweden. J. Glaciol., **34** (117), 242–248.

Isenko, E. V. (2005): Development and evolution of water drainage channels in temperate and polar glaciers. Ph. D. Dissertation, Sapporo.

Isenko, E. V., Naruse, R. and Mavlyudov, B. R. (2005): Water temperature in englacial and supraglacial channels: change along the flow and contribution to ice melting on the channel wall. Cold Regions Science and Technology **42**, 53–62.

Potts, M. K. (1950): Mount Rainier’s greatest ice caverns. Pacific Discovery, v. **3**, N 3, 5–7.

Reynaud, L. (1987): The November 1986 survey of the Grand Moulin on the Mer de Glace, Mont Blanc Massif, France. J. Glaciol., **33** (113), 130–131.

Röthlisberger, H. (1972): Water pressure in intra- and subglacial channels. J. Glaciol., **11** (62), 177–203.

Zotikov, I. A. (1982): Thermal physics of glacial sheets. Leningrad, Gidrometeoizdat, 288 p. (In Russian).